2018

Protocol for Energy Efficient Cluster Head Election for Collaborative Cluster Head Elections.

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Protocol for Energy Efficient Cluster-Based Routing for Collaborative Wireless Sensing.

by

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This Report is submitted in partial fulfilment of the requirements of the Master of Science Degree in Electronics and Communications Engineering (DT086) of the Dublin Institute of Technology

September 7th, 2018

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Declaration

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Dublin, 7th September 2018

(David Otu)

Acknowledgements

I wish to express my sincere gratitude to our supervisor Dr. Ruairí de Fréin, School of Electrical and Electronics Engineering, Dublin Institute of Technology, for his scholarly advice and assistance. Without his guidance and support, this project would have been unachievable.

I also want to appreciate my course mates for excellent cooperation in sharing knowledge and help in understanding difficult topics throughout the program. They were a huge source of morale and motivation. I am very grateful for having them as course mates.

Finally, and most of all, I wish to thank my mother, Mrs. Otu who made the year in Ireland possible and supported me all through the years.

Abstract

In wireless sensor networks (WSNs), energy is a major constrain. Energy efficient network protocols is required to maintain reliable sensing of the sensing field. WSNs that use LEACH protocol, have node in a cluster periodically take trials to become cluster-head, such that the nodes in the cluster becomes cluster-head evenly. Nodes with greater transmission distance to the base station in the cluster dies out faster because it performs more work in transmitting data when it is cluster-head. The distance-based algorithm presented in this project, ensures that work is allocated to the nodes in the cluster more evenly, thus, all areas of the sensor field is sensed more reliably.

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1. Introduction

In recent times, the use and importance of sensor networks is on the increase due to the availability of cheap, low power micro-sized components integrated on a single chip. Wireless sensors enable sensing of an environment, which connects us to our environment in ways that seemed impossible few years back. The sensor gathers useful information about the environment such as temperature, pressure, motion, vibration, sound and more. Various sensor nodes are used to sense different parts of the environment, this requires information and communication technologies to aggregate and transmit the sensed data to the application servers for translation to useful information. Wireless sensor networks (WSNs) provide this platform [20].

A WSN can generally be described as a network of nodes that "cooperatively sense and may control the environment, enabling interaction between persons or computers and the surrounding environment" [1]. Regularly, hundreds of sensor nodes are deployed in the sensing field. The sensor nodes are equipped with sensing and processing devices, radio transceivers and a power source. Sensing, processing and communication is carried out using a limited amount of energy. Power is a major resource constraint in wireless sensor nodes. Highly energy efficient network protocols are required for a reliable wireless sensor network in order to delay individual node failures and prolonging the lifetime of the network.

The rapid increase of smart phones with increasingly sophisticated sensors provides an attractive platform for mobile sensing. Some applications require environments constituting of mobile and static sensor nodes within the same network, while other applications require complete mobile or static sensors environment [8]. For example, in wild life exploration where sensors are attached to animals to observe their behaviours in various habitat [9], mobile devices are also used for acoustic environmental sensing [18][19].

1.1 Motivation

Mobile sensing is a very attractive platform for sensor networks due to increase in the number of smart phone users and sophisticated embedded sensors on the smart phones, such as accelerometer, gyroscope, digital compass, etc. Mobile sensing applications abound in areas such as health-care, environmental monitoring, transportation, safety and more [10]. A major constraint is energy-efficiency. Mobiles exhaust extra energy when transmitting application specific detected information over cellular network when Wi-Fi is unavailable. Then again, the mobiles don't report their sensor readings, and the accuracy of the system is influenced.

Several algorithms have been developed to improve the energy efficiency of wireless sensor networks, one of such algorithm is LEACH (Low-Energy Adaptive Clustering Hierarchy) algorithm [11]. LEACH is a cluster-head election-based algorithm, which prolongs the network lifetime by efficiently utilizing the energy of each node. Cluster-head protocols involve nodes in the network forming clusters and a node is elected cluster-head. Cluster-heads control the interaction on nodes in it cluster and transmits to the base station where the data in interpreted to useful information. This LEACH model can be explored and improved upon for better performance and energy efficiency. For instance, in LEACH, the distance and energy of sensor nodes is not considered. This can be further optimized during cluster-head set-up for improved efficiency.

1.2 Problem Statement

WSNs are sometimes used over wide areas and the sensors have limited battery capacity. Sensors can communicate with different nodes of the sensor network and the base station, they greater the distance between the communicating nodes or node to base station the greater the energy required for transmission. In addition, in a sensor field consisting of hundreds of sensor nodes, relatively more energy in total is spent when all nodes are communicating with the base station compared to when a cluster-head gathers information to be transferred to the base station from nodes in the cluster that is usually in close proximity [11]. If the all nodes in the cluster become cluster-head evenly, the nodes that are further away from the base-station die out faster due to more work done to transmit data to the base station when elected cluster-head.

1.3 Aim of Thesis

This project will study the design of energy-efficient stochastic leader-selection algorithms in sensor fields of mobile sensors. This work will optimize the energy usage of the interaction between mobile handsets and an application server. The energy-efficiency of mobile handset communications is of increasing importance given the convergence of mobile computing and cloud computing. In some scenarios, the lack of Wi-Fi forces mobile devices to expend additional energy transmitting application specific sensed data over cellular networks. This project will focus on:

- Allocating the overhead of transmitting sensed data to a cellular base station amongst the mobile devices by selecting a cluster-head in a fair manner (Fairness is measured in terms of the relative energy expended);
- Considering the relative distance of nodes in the WSN to make energy consumption more fair.

1.4 Methodology

This project involves evaluating the energy consumption of different approaches to the afore-mentioned aim. The project is simulated in Simevents, which is part of the Simulink package for Matlab, because SimEvents allows us to investigate, discrete event processes and to develop an initial understanding of how a complex system would work.

1.5 Scope of Thesis

In this segment, a review of all parts in the report is given with a short portrayal of everyone. Chapter 2, Preliminary investigation, describes basic WSN operation, sensor node functionality and energy requirement for different access technology, algorithms and simulation tool used during this work.

Chapter 3, Implementation, explains all the process of coding followed in this work. With all the necessary background information explained, how the cluster-head selection algorithm on a single node works, the mobility model used [15], how the energy consumption block functions. All the details and decisions taken during the process are analysed in this chapter.

Chapter 4, System performance, shows the results obtained from performing the experiments described in the evaluation chapter.

Chapter 5, Conclusions, shows the interpretations of the results explained on the previous chapter. These interpretations are the outcome of the work of this thesis and their meaning and relevance are explained in this chapter.

Finally, Chapter 6, Future Work, the future works of interest exposed during the realization of this project is contained in this chapter.

2. Preliminary Investigation

2.1 Wireless sensor network (WSN) Technology

A WSN can generally be described as a "network of nodes that cooperatively sense and may control the environment, enabling interaction between persons or computers and the surrounding environment" [1]. A typical WSN consist of a base station (or sink) and sensor nodes which may be mobile. The base station is an interface between users and the network. Many sensor nodes are scattered randomly around or near the sensor field (monitored environment).

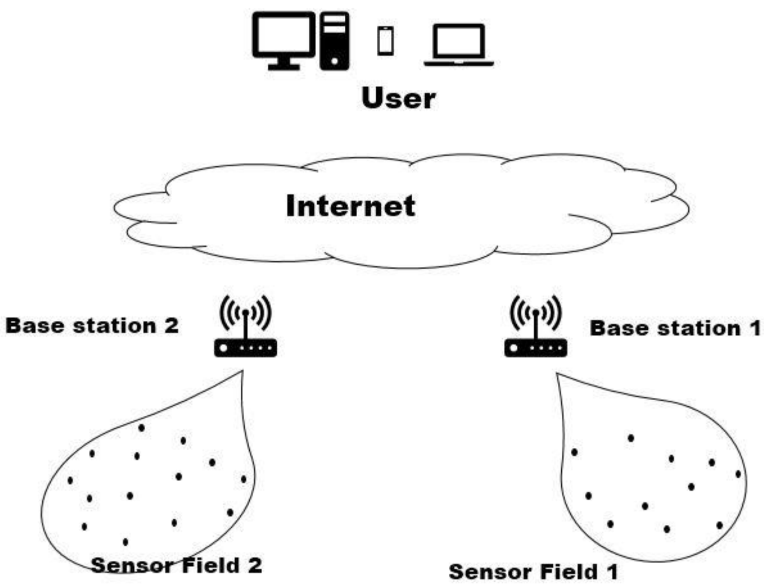

Figure 2.1: WSN schematic

Figure 2.1 shows two sensor fields with multiple nodes that send their sensed data to their respective base station. Power limitation is typically not a major constraint of the base station, therefore, has more processing power, and speed to collect data and send to the end users as required. The sensor nodes typically form a multi-hop (or it may be a single-hop to the base station) mesh network through established communication links to neighbour nodes. When cluster-based network protocols are used, the nodes are combined into clusters, the elected cluster-head collects the data in its cluster and transfers to the based station. This reduces network overload. Where sensor fields are large, multiple base station are used and long-range high-speed communication is established between the base stations.

2.1.1 Sensor node

The wireless sensor node consists of four major components: the sensing unit, the processing unit, the transceiver unit and the power unit. The sensing unit is sensitive to the required data (e.g. temperature, light, pressure, gas/chemicals etc.) and converting to electrical signals which is transferred to the processing unit. The processing unit processes the signal from the sensing unit accordingly. The transceiver unit receives and transfers data at a limited range. The power unit supplies power to all the component of the sensor node.

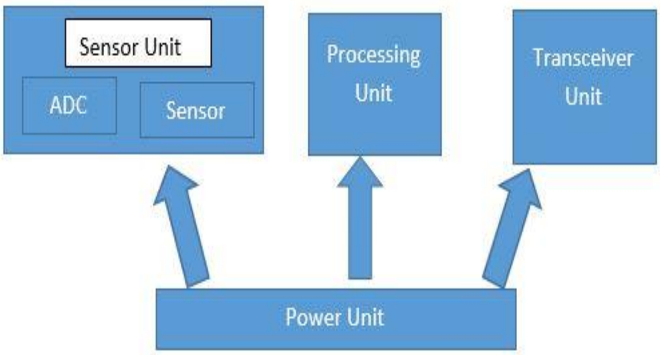

Figure 2.2: Structure of sensor node

In figure 2.2, the sensing unit consist of sensor which is sensitive to the required data (e.g. temperature, light, pressure, gas/chemicals etc.) and analogue-digital converter (ADC) converts the sensed signals to electrical signals and then transferred to the processing unit. The processing unit processes the signal from the sensing unit as required, for instance, compression of the sensed signal in order to make transmission more efficient [2][21]. The transceiver unit receives and transfers data using a technology such as Bluetooth, Wi-fi or ZigBee. The power unit supplies power to all the component of the sensor node.

2.1.2 Access network technologies

The access network in WSN refers to how the various sensor nodes connect to each other and the base station. Typically, WSN applications require the access network to be reliable due to narrow-band multi-frequency noise, interference and multi-path effects in the sensor field. Also, many applications of WSNs require strict real-time communication; a delay in communication may lead to a major accident as in the case of industrial or medical use. The access network is also required to be power conservative due to the energy constraint of the sensor nodes. Following the specific requirements of WSN application, the access network often uses Bluetooth, ZigBee (IEEE 802.15.4), WLAN (IEEE 802.11) transmission technologies, also cellular networks for mobile sensing applications.

Bluetooth low energy (BLE) technology provides personal area communication capabilities to the nodes while consuming ultra-low power. It operates in the 2.4GHz, has a range of about 50m, over the air data rate of 1Mbit/s at which the signal hops 79 frequency, giving it a high noise immunity [3].

ZigBee is built upon IEEE 802.15.4 standard, designed to provide low cost and low power consumption for low data rate applications. It can be easily implemented in larger networks than Bluetooth as it permits mesh topology while Bluetooth uses star topology. ZigBee wireless devices operate in the unlicensed RF worldwide (2.4GHz global, 915MHz Americas or 868 MHz Europe). The data rate is 250kbps at 2.4GHz, 40kbps at 915MHz and 20kbps at 868MHz [4].

WLAN technology is built on the IEEE 802.11 standard and has many communication protocols varying in their characteristics as data rate or bandwidth. Wi-Fi is viable for WSN because of its compatibility between various devices. The size, cost and power requirements of Wi-Fi (802.11) has decreased dramatically since the introduction of 802.15.4. It has a range of about 100m and data rate of 54Mb/s.

	Peak current consumption	**Range**	**Data rate**	**Relative cost**	**Topology**
ZigBee (802.15.4)	30mA	50m	250Kb/s	Low	Star/mesh
Bluetooth low energy	15mA	100m	1Mb/s	Low	Star
Wi-Fi (802.11b)	~100mA	100m+	11and 54Mb/s	Medium	Star

Table 2.1: Summary of access network technologies [3][4][5]

Third generation (3G) mobile communication is widely available and have a very large range. 3G power consumption is not only related to the data transmitted, but also to network parameters such as buffer thresholds or inactivity timers [6]. Energy consumption is mostly influenced by Radio Link Control (RLC) protocols and the Radio Resource Control (RRC) protocols. The RRC enables the user equipment (UE) to operate in different states which vary in power consumption and performance [7].

2.1.3 Energy consumption model

This project uses a simple radio consumption model to express the energy consumption. This radio model offers an assessment of energy consumed when a sensor node transmits or receives data at each cycle [11]. The radio has a power control to consume minimum energy required to reach the intended nodes.

The number of bit in a message is assumed to be fixed, k, transmitted through a distance, d, energy required for transmission cancan be expressed as:

$$E_T = E_e.\ k + E_a.k(J) \qquad (1)$$

And the energy consumed at the receiver is expressed as:

$$E_R = E_e.k(J) \qquad (2)$$

Where E_T is the energy dissipated at transmitter (Joules), E_R is the energy dissipated at receiver (Joules), E_a is the energy dissipated in transmit amplifier (J/bit/m^2), the circuit energy when transmitting or receiving k bit of data is E_e (J/bit), and d is the distance between a sensor node and its respective cluster-head or between cluster-head and base station. Using the peak current consumption, the E_e during peak transmission for different access point using 3 volt CR2023 battery in displayed in the table below.

	ZigBee	**Bluetooth**	**Wi-Fi**
E_e (nJ/bit)	360	45	150*

Table 2.2: Energy per bit for different technologies.

The table above is an estimation of energy per bit of the different access technology but varies markedly between supplies of the different chips. The cost of Wi-Fi in table 2.2 is measured using data rate of 2000Kbs.Wi-Fi has high peak current but has higher power efficiency as compared to the other two (2) technologies when running at full speed.

This project focuses on optimizing the energy consumption due to data communication subsystems, which is the dominant source of energy dissipation in sensor nodes [11]. The approach neglects energy consumed by the sensing and processing unit. The distance from the node to the base station is assumed to be greater than the distance between the sensor nodes. Hence, the transmission between the nodes is at a cheaper cost than node to base station. It is assumed each node has equal transceiver and processing capabilities, which transmit the sensed data every S seconds. Distance between node A and B, d_{AB}, is given by:

$$d_{AB} = \sqrt{((x_A - x_B)^2 + (y_A - y_B)^2)} \qquad (3)$$

The above formula represents the Euclidean distance between the nodes or node to base station. The protocol involved in the network could imply the nodes transmitting data directly to the network (direct communication) or multi-hop transfer to the base station through consequent node between the base station and the communicating node (peer-to-peer communication). Consider the linear network below:

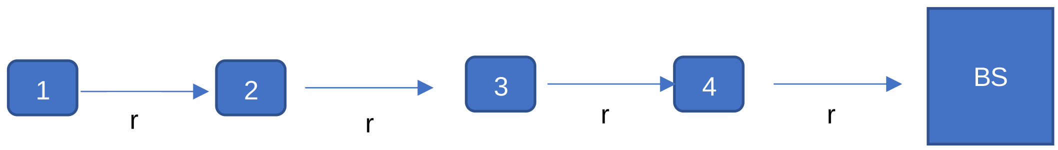

Figure 2.3. A linear network

The network above consists of four nodes with distance, r, between them and a base station. For direct communication to the base station, cost is:

$$D = E_e. k + E_a .(nr)^2.k \qquad (4)$$

$$D = k[E_e + E_a .n^2r^2]$$

Where nr = d, the distance to the base station. For multi-hop communication, the data is received and transmitted n times to get to the base station, the cost is:

$$M = n .k[E_e + E_a .r^2] + (n-1) E_e .k \qquad (5)$$

Multi-hop communication may cost more energy than direct communication depending on the radio circuitry used and the transmitter amplifier. Condition for direct communication to be less than multi-hop communication is:

$$\mathrm{D} < \mathrm{M}$$

$$\mathrm{k}[E_e + E_a.n^2.r^2] < \mathrm{n.k}[E_e + E_a.r^2] + (\mathrm{n} - 1)E_e.k$$

$$E_e + E_a.n^2.r^2 < \mathrm{n}[E_e + E_a.r^2] + (\mathrm{n} - 1)E_e$$

$$E_e + E_a.n^2.r^2 < E_a.\mathrm{n}.r^2 + (2\mathrm{n} - 1)E_e$$

$$E_e - (2\mathrm{n} - 1)E_e < E_a.\mathrm{n}.r^2 + E_a.n^2.r^2$$

$$(2 - 2\mathrm{n})\, E_e < E_a\,.r^2(\mathrm{n} - n^2)$$

$$E_e < \frac{E_a\,.r^2(\mathrm{n} - n^2)}{(2 - 2\mathrm{n})}$$

$$\frac{E_e}{E_a} > \frac{\mathrm{n}.r^2(1 - \mathrm{n})}{2(1 - \mathrm{n})}$$

$$\frac{E_e}{E_a} > \frac{\mathrm{n}.r^2}{2} \qquad (6)$$

If the condition in equation (6) above is satisfied, the direct communication is less than multi-hop communication.

2.2 Cluster-head algorithm

Proper grouping of nodes into clusters minimizes energy. Clusters group a number of nodes in the network (typically based on distance), thereby, reducing the number of communicating nodes. A node is selected as cluster-head in each node based on some criteria (for example energy of node, distance to base station). Cluster-heads receive data from nodes in its cluster, combine the data and transfers the data to the base station. Using cluster approach increases the network lifetime during routing as the scalability reduces load, and energy consumption [12][13].

In this project, the cluster-head election approach is based on LEACH algorithm. During the cluster-head selection process, each node generates a random number between 0 to 1, then compares to the threshold value (T). If the random number is less than the threshold value, the node is a cluster-head for that round of election [14]. If x is less than the T value at that instance, the node is a cluster-head. The output is:

$$Y = \begin{Bmatrix} 0, & x \geq T \\ 1, & x < T \end{Bmatrix} \quad (7)$$

The threshold, T is given by:

$$T = \frac{p}{1-p(r mod \frac{1}{p})} \quad (8)$$

Where p is the probability of the nodes becoming cluster-head and r is the election round number. The probability of becoming cluster-head for all the nodes is the same. The threshold value is a cyclic function of p, with 1/p rounds. At round 1/p-1, the probability of node becoming cluster-head is ‘1’. Nodes can become cluster-head multiple times provided the criteria above to be cluster-head is met. Increasing the value of p increases the number of nodes that would become cluster-head. LEACH does not take to consideration the distance when electing the cluster-head, in this algorithm, the probability of becoming a cluster-head is a function of distance from the base station.

2.3 Levy walk-around model

This project makes use of Levy walk-around model to incorporate mobility of the nodes. Naturally, animals make moves in search of food in random directions and distances. Levy walk is a type of random walk in which each move has a random direction and length and not depending on the previous move. Most of the moves are usually in a small area or short length, then occasionally, the move has a long distance.

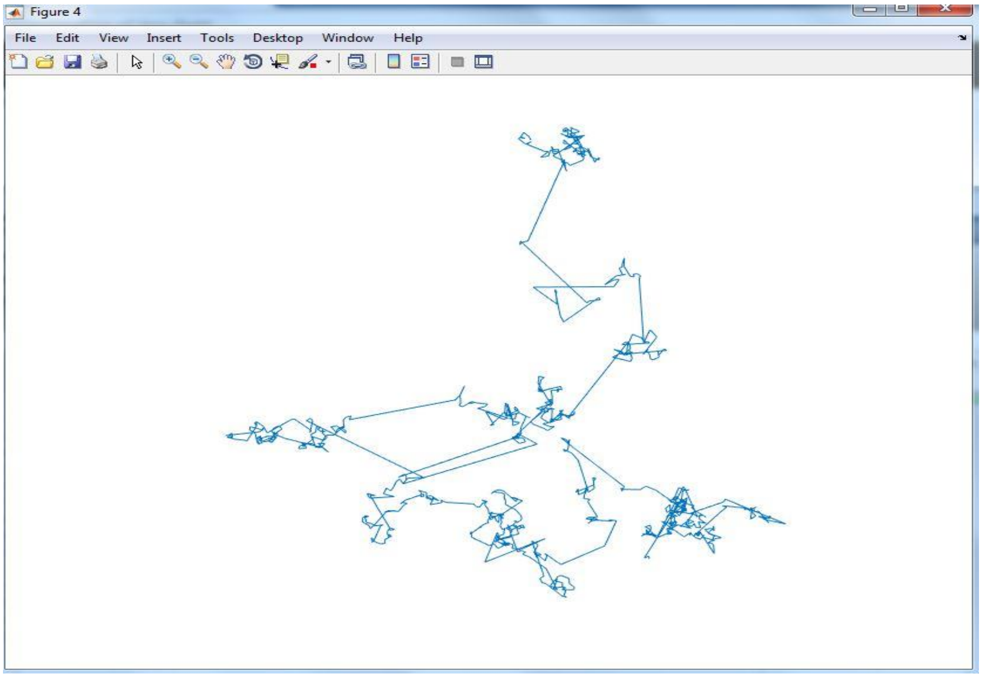

Figure 2.4: Levy walk path (100 steps)

It has been demonstrated that people wandering around university campuses, Disney world and urban environment have a pattern very similar to Levy walk [15]. Levy walk is incorporated into the mobility of the nodes for accuracy and more realistic network simulation.

2.4 SimEvents

SimEvents is a Simulink extension for MATLAB that allows modelling and simulation of discrete-event systems. In SimEvents, a graphical drag-and-drop interface is provided for assembling and using models [16]. By SimEvents, it is possible to design routing, processing hold-ups, and prioritization for scheduling and interaction using lines, servers, switches, and other pre-existing block[17].

Using SimEvents, a discrete-event simulation model can be created to simulate the passing of entities through a network of queues, servers, gates, and switches based on events [16]. This project makes use of SimEvents to simulate the algorithm of the WSN nodes, efficiently estimate the performance and cost of the system, and obtain accurate conclusions from the results.

3. Implementation

In this chapter, the processes involved in the actualisation of the algorithms are discussed. SimEvents is used to simulate the cluster-head algorithm on a single sensor node. The distance between nodes and the base station is computed in the MATLAB script, which is used to compute the energy consumption. Simulation for static nodes is run and energy readings are recorded. Then the simulation is run with LEACH implemented, and the energy readings and battery lifetime are observed. For the battery lifetime, each node initially has energy of 2J. As the simulation is run, energy consumed given by equation (1) in Chapter 2 is subtracted from the initial node energy, which is used to estimate battery lifetime. The algorithm this project is contributing, where the probability of the nodes becoming cluster-head is influenced by the distance of the node from the base station and energy readings are observed.

3.1 Direct communication

In this simulation, the nodes are in close proximity to each other and the base station is positioned far away. All the nodes will communicate directly to the base station.

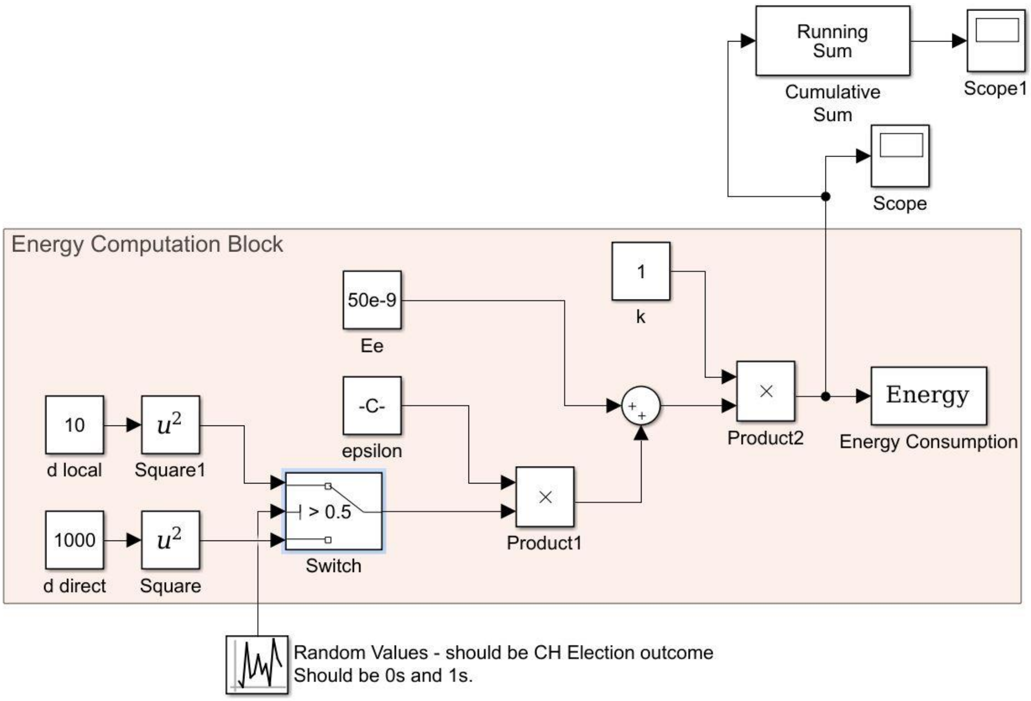

Figure 3.1: The energy consumption block. © Copyright Ruari de Fréin, June 2018.

The energy consumption of 7 nodes located between 900-1100m from the base station is simulation using the above model in Simulink. The node sends data every 60secs to the base station. The radio circuitry, E_e, consumes 50nJ/bit and transmitter amplifier, E_a, consumes 100pJ/bit. The maximum random value used by the switch is set to less than 0.5, so that communication is direct for the nodes. In this project, number of bits per transmission, k, is assumed to be '1' for simplicity. The simulation is run for 12000secs where the cumulative sum of energy spent is recorded.

3.2 LEACH IMPLEMENTATION

The LEACH algorithm is setup in SimEvents using mathematical blocks to solve the equation (4) and (5) in chapter 2. This is shown in Figure 3.2 below.

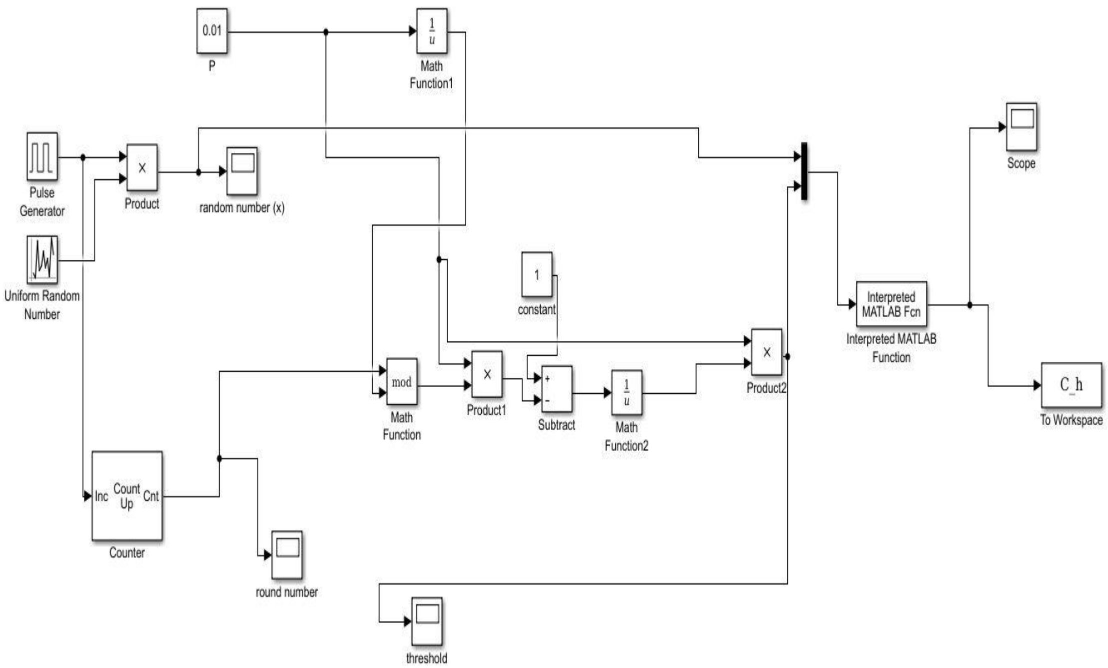

Figure 3.2. LEACH algorithm model

The model in figure 3.2 defines the cluster-head algorithm of the sensor node. The pulse generator is set-up to generate a pulse every 60 seconds, which is used to generate the random number that is compared to the threshold value to determine if the node is cluster-head. Therefore, cluster-head election takes place every 60 seconds. The random number generator for the different nodes is configured with different initial seed and sampling time so as to generate different random numbers for the nodes. The counter attached to the pulse generator is the round number used in the modulus function in equation 5. The value of the p is implemented using the constant block in SimEvents. The threshold function is a seesaw-like function shown in figure3.3 below.

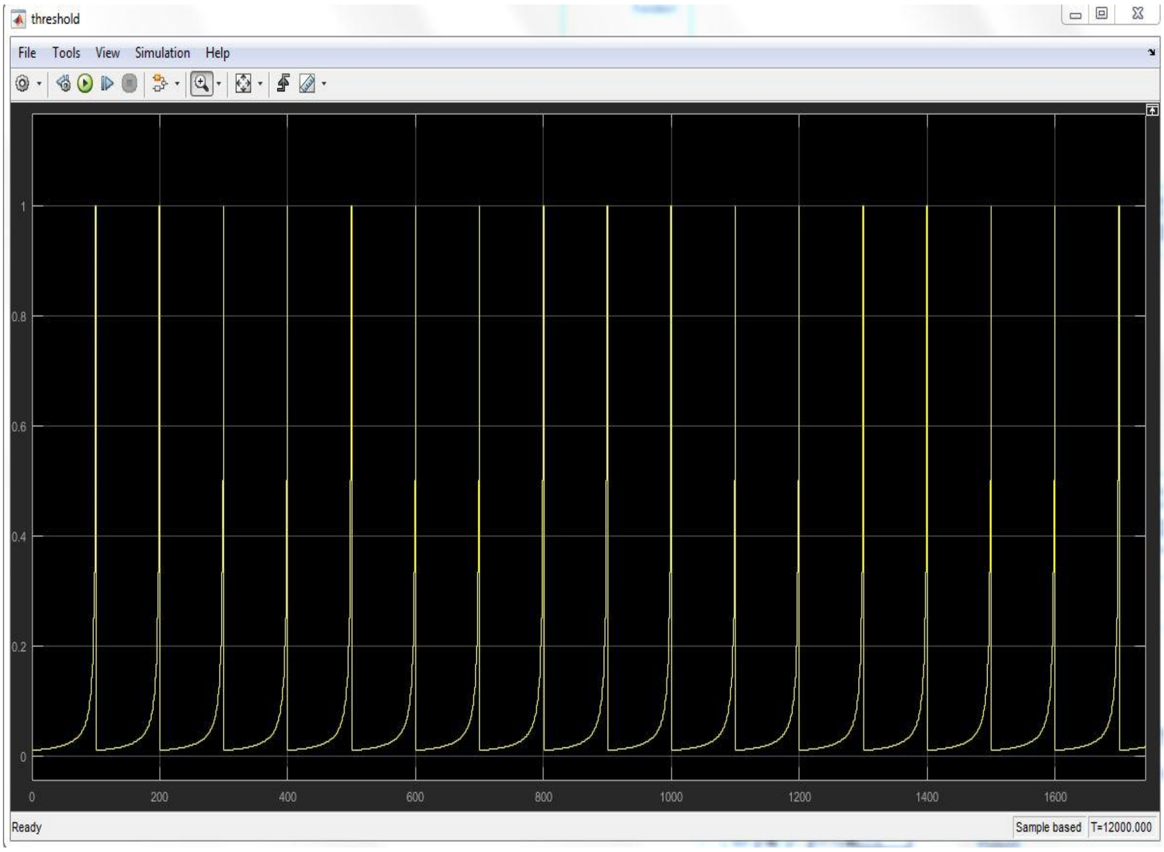

Figure 3.3: Threshold function

Figure 3.3 shows the threshold form generated using p value of '0.01'. The p value controls the threshold function. The threshold is minimum at the first round and maximum when the cluster-head election round is a multiple of 1/p -1, when the cluster-head election round is a multiple of 1/p, the threshold starts from minimum again. This allows nodes to be coming cluster-head at least once after every 1/p rounds.

The MATLAB function block in figure 3.2 compares the threshold to the random number generated and outputs '1' if the random number is less than the algorithm threshold (meaning the node is cluster-head for that election round), else outputs '0' (meaning node is not cluster-head). The simulation is run for 12000 seconds and the cluster-head election result is read into MATLAB workspace.

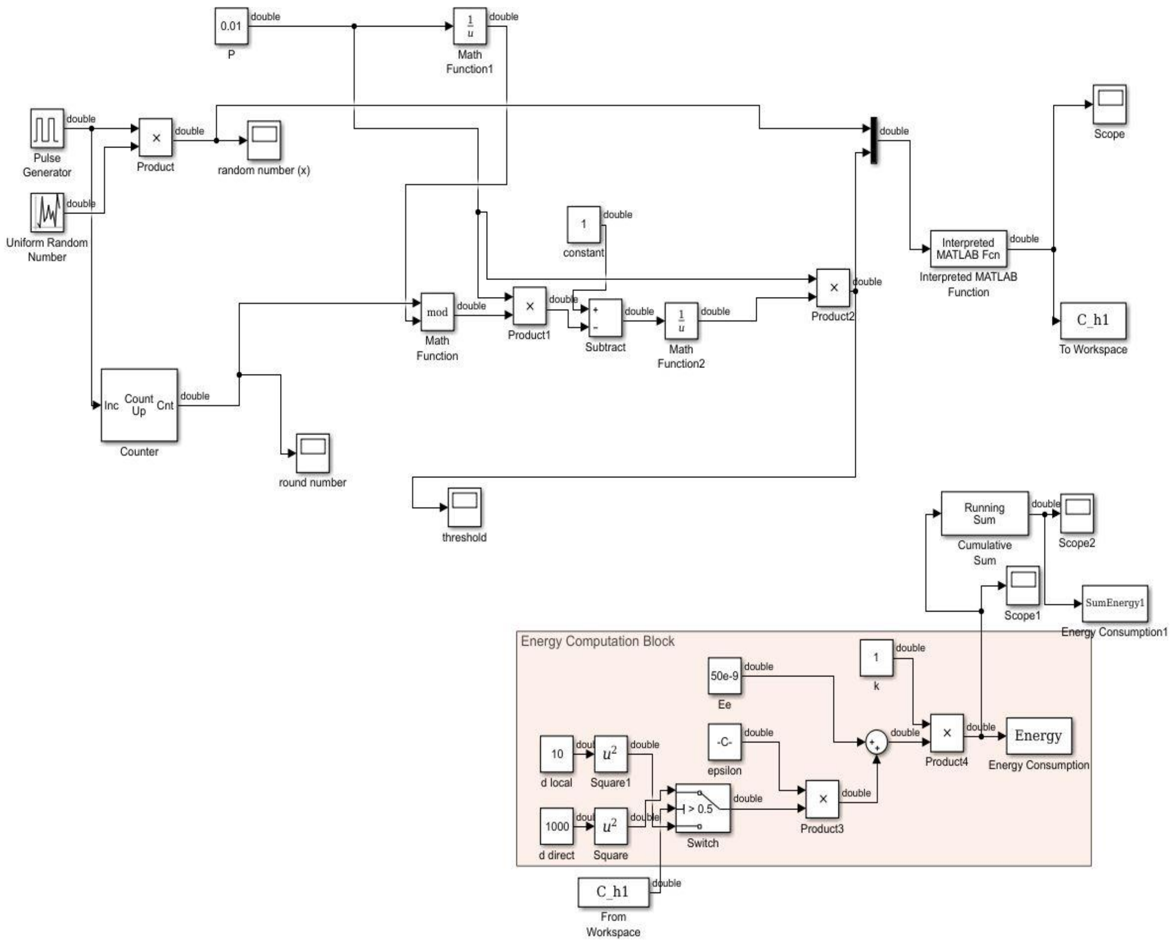

Figure 3.4: Model of a single node. I would like to acknowledge Ruari de Fréin for providing the "Energy consumption block" below. ©Copyright R. de Fréin 2018.

The cluster-election result is used to switch to either local communication (to cluster-head) or direct communication to base station. If the output from the cluster-head election result is greater than '0.5', the switch allows the distance to the base station pass through and is multiplied by the value of energy consumed per bit by the transmitter amplifier (epsilon in figure 3.3) which is set as 100pJ/bit. The bit per transmission, k, is set at 1. The energy consumed by the radio circuitry, E_e, is set using table 2.2 for the different technologies. The energy consumed per transmission is observed at the 'Energy' block, while the total energy consumed at the end of the simulation time is observed at the 'SumEnergy' block.

3.3 Node mobility

The mobility of the node is incorporated using truncated Levy walk model described in reference [15]. The Levy flight and pause time used in this model is determined from Levy distributions with stability exponents $\alpha = 1.5$ and $\beta = 0.5$. This project assumes the base station is far away from the nodes. The base station is configure to have coordinates [500,500]. The Levy walk function is run for 200 steps in MATLAB and the coordinates are read into the nodes in Simulink. The Levy walk is run for the 30 nodes in the network model, this is shown in Figure 3.4.

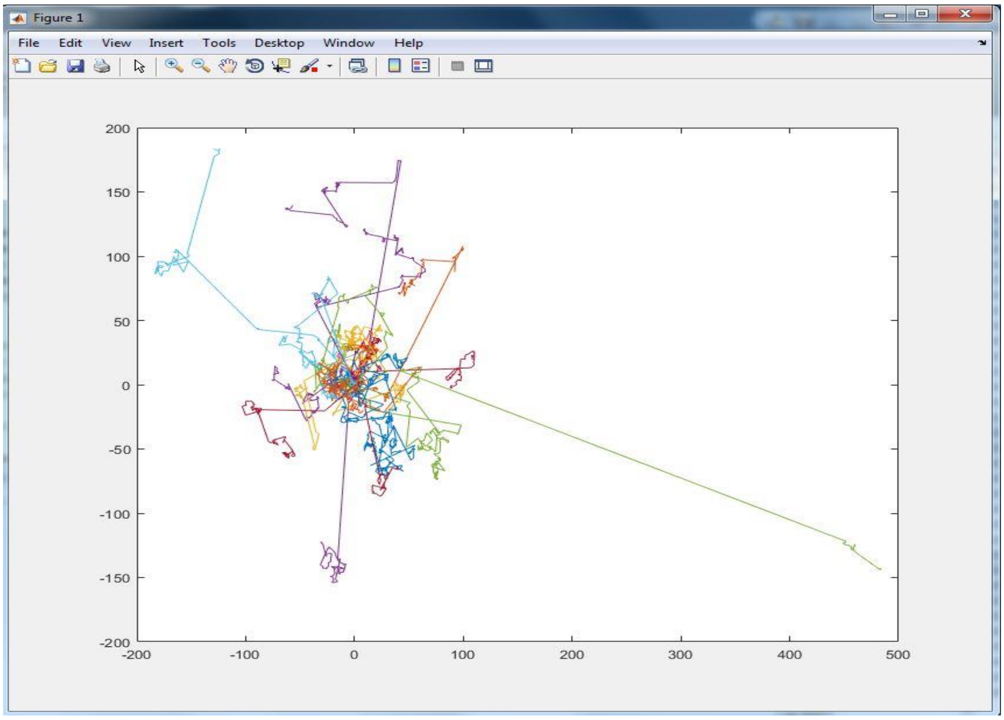

Figure 3.5: Levy walk for 30 nodes

The Euclidean distances between the node and the base station are read into the Simulink model. The distance to the base station is read into the direct distance block while for the local distance block (used for p2p communication) the mean distance between the nodes is computed in MATLAB and used as the local transmission distance.

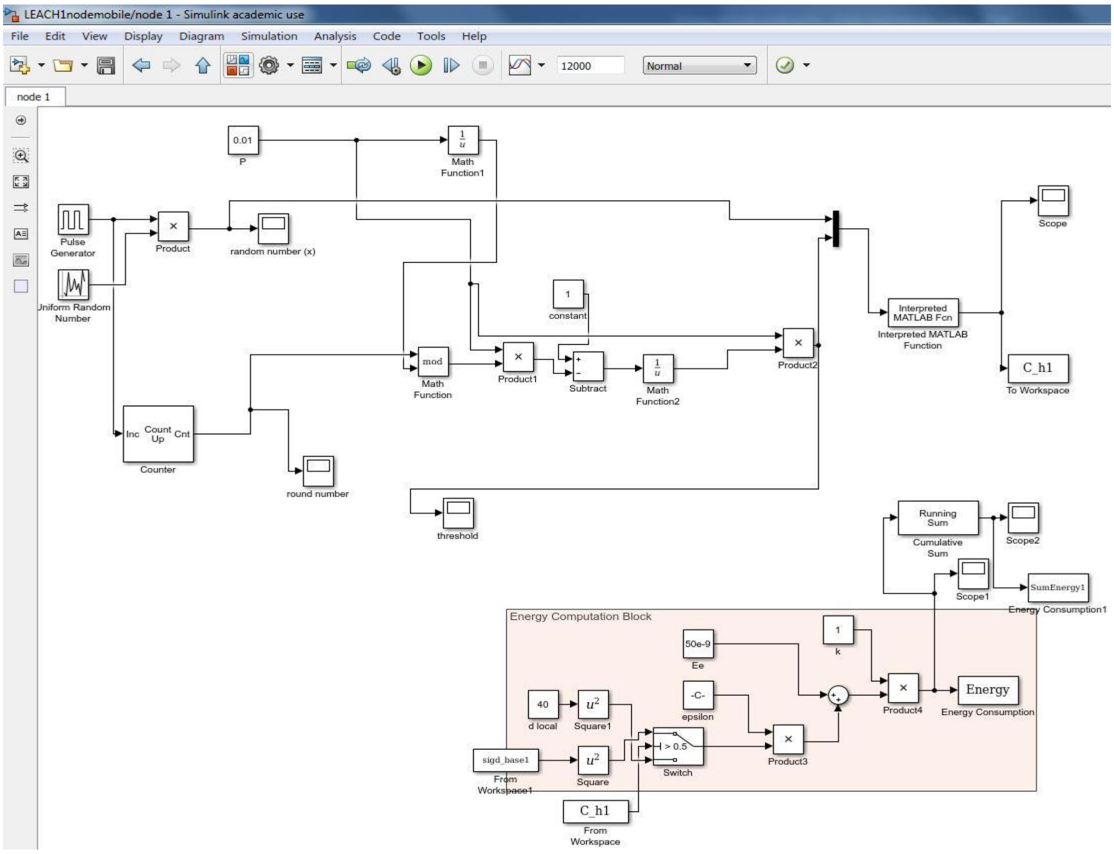

Figure 3.6: Model of a mobile node. Energy consumption block (bottom) ©Copyright R. de Fréin 2018

Figure 3.5 shows the distance of the node from the base station is read into the energy consumption block of the node from MATLAB workspace, using the from workspace block. The switch switches between local transmission distance and direct transmission distance depending on the cluster-head status of the node at that instance. The distance of the node to node or base station is read in every 60secs.

3.4 Distance-based cluster-head election

The goal here is to have the probability of becoming cluster-head for the nodes that are further away from the base station to be less than nodes closer to the base station. This will cause more work to be allocated to the nodes closer to the base station. This is implemented by modulating the threshold value for the nodes. The probability of the nodes becoming cluster-head is multiplied by a weighted valued influenced by the nodes distance from the base station. The weight value is given by:

$$\text{Weight} = \frac{1}{N \text{ x } d_n^2 \text{ x D}} \qquad (6)$$

$$\text{D} = \frac{\frac{1}{d_1^2}+\frac{1}{d_2^2}+\frac{1}{d_3^2}...+\frac{1}{d_N^2}}{N}$$

$$P_d = \text{p x weight} \qquad (7)$$

Where D is the mean inverse distance square between all the nodes in the network and the base station, dn is distance of a given node to the base station and N is the number of nodes in the network. This way, if the node is further away from the base station, the probability of becoming cluster-head is less than the nodes closer, effectively increasing the number of rounds for the threshold value to recycle and ultimate reducing the work for that node. For the static node, Pd is computed and MATLAB and the p value of the node is changed to the P_d value. For mobile nodes the P_d value is computed as shown in Figure 3.6.

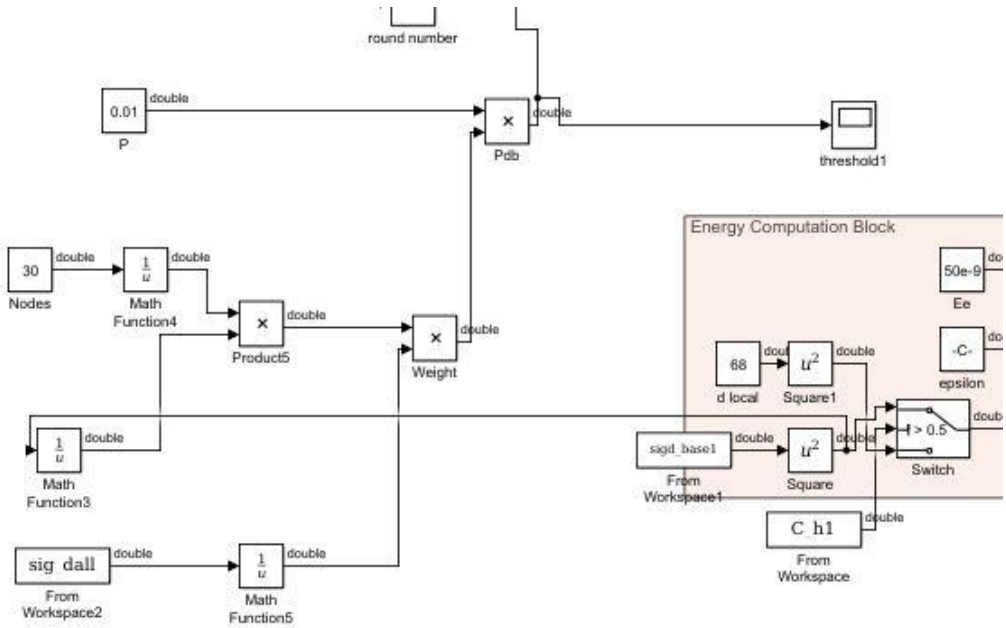

Figure 3.7: mobile node using distance-based algorithm

Figure 3.6 shows the computation of the distance-based probability for a mobile node. The mean inverse distance square between all the nodes in the network and the base station, D, read into the mobile node. D is computed and read from MATLAB workspace into Simulink using the 'From Workspace' block labelled 'sig_dall'. The inverse of the node distance to base station, the inverse of D value, the inverse of the number of node and the p value is multiplied and the output feeds the threshold algorithm as the new p value.

4. System Performance

The simulation results and analysis are presented in this chapter. Static nodes and mobile nodes are simulated and analysed. In this analysis, nodes communicating directly with the base station, nodes operating with LEACH algorithm and nodes with distance based cluster-head algorithm are simulated.

4.1 Static nodes

4.1.1 Direct communication

The energy of seven (7) nodes with positions at different distance between 900 m and 1100m from the base station are shown in table 4.1.

Node	**Distance (m)**	**Energy (mJ) at 12000s**
1	920	16.94
2	940	17.68
3	960	18.44
4	980	19.22
5	1000	20.02
6	1020	20.82
7	1040	21.64
	Total	134.76

Table 4.1 energy consumed using direct communication

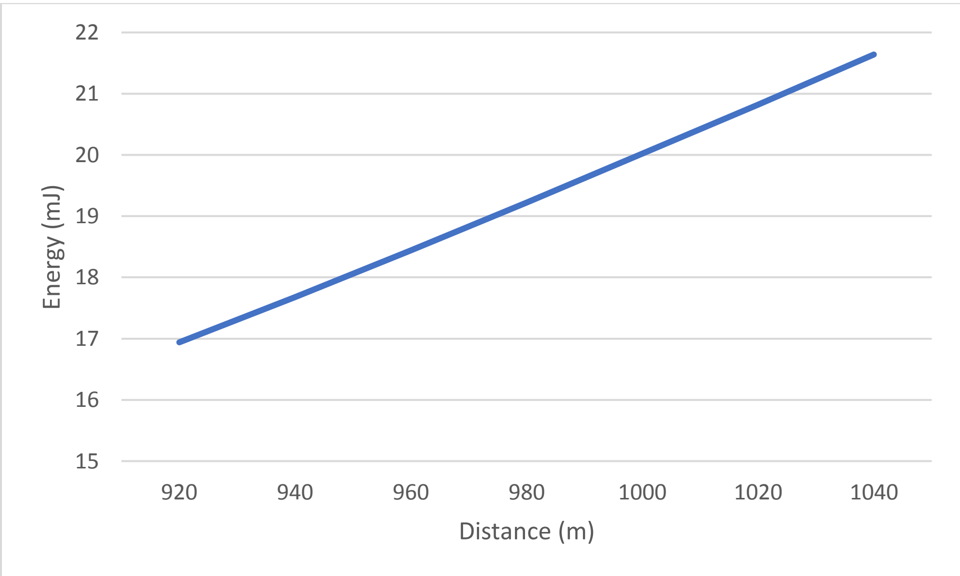

Figure 4.1 Graph of Energy consumed vs distance

The graph in Figure 4.1 shows that the distance of transmission is linearly proportional to the energy consumed during direct transmission with the base station. More energy is required when transmitting to the base station. Giving the seven nodes an initial energy of 2J and running the simulation longer, with nodes transmitting to the base station every 60 seconds, node 7 dies on transmitting 18484 times (18484minutes) to the base station, this is significantly shorter time than node 1. This results in unaccurate data, because some areas will not be sensed.

The different network access technologies (that is Bluetooth, ZigBee and Wi-Fi) dissipate different power for transmission as shown in table 2.2. The energy impact of using these different technologies is shown in Figure 4.2.

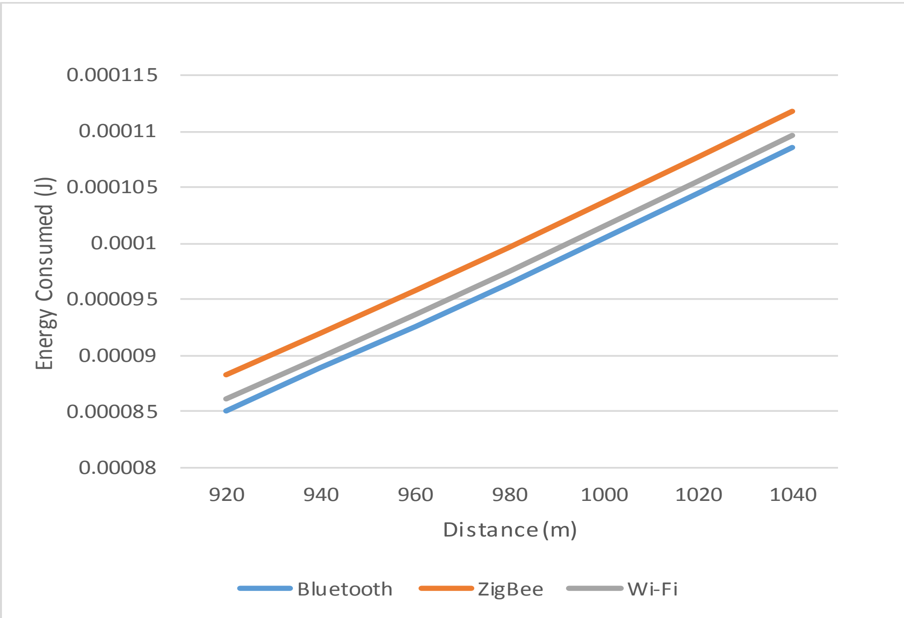

Figure 4.2 Graph of Energy consumed vs distance vs technologies

Figure 4.2 shows that Bluetooth transmits at lower energy than Wi-Fi and ZigBee due to its low peak current and high data rate. The figure is plotted with Wi-Fi configured to transmit at 2Mbps. Wi-Fi has higher peak current requirements than ZigBee but significantly higher data rate, this is the reason W-Fi consumes lower energy in the network.

4.1.2 Energy consumption of LEACH

On implementing LEACH algorithm in the network, the effect of the probability of becoming cluster-head, p on energy consumption is measured for $0.01 < p < 0.1$ with increment of 0.1. The relationship is shown in Figure 4.3 below.

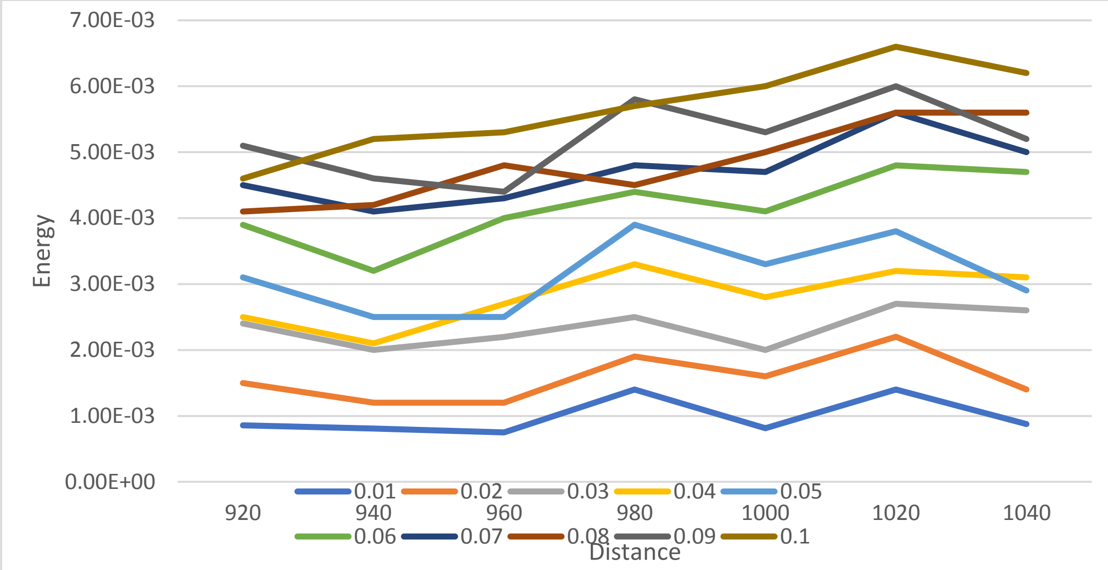

Figure 4.3 Graph of Energy consumed vs cluster-head probability

Figure 4.3 shows that choosing a higher probability for the nodes becoming cluster-head results in higher energy consumed due to node to base transmissions when the node is cluster-head. An in-depth study of the optimum ‘p’ such that a node in the cluster is always cluster-head and not too many nodes being cluster-head.

Using one percent (1%) probability of node becoming cluster-head, using Bluetooth technology, the distance, energy consumed after 12000 seconds and number of times node becoming cluster-head is shown in table 4.2.

Node	Distance	Energy (J) at 12000s	No of times CH
1	920	8.58E-04	10
2	940	8.07E-04	9
3	960	7.49E-04	8
4	980	0.0014	14
5	1000	8.12E-04	7
6	1020	0.0014	13
7	1040	8.77E-04	8
	Total	6.90E-03	

Table 4.2. Energy consumed using LEACH

From the Table 4.2, it is observed that nodes that become cluster-head more often over a period, have greater energy consumed than nodes that were rarely cluster-head because of the energy expended in transmitting to the base station. Node 5 became cluster-head less than node 3 and 2 but still consumed more energy than both because it has a greater transmission distance. This is the same reason node 7 expends more energy than node 1,2 and 3. Observing 7 nodes of the network with same distance from the base station as direct communication, the energy consumption using LEACH has a 95.42% decrease compared to direct communication. Giving each node an initial energy of 2J, and running the simulation longer, node 7 dies after 456100 cluster-head elections of which within that interval (60 seconds), if it is cluster-head, the node transmits to base station, else p2p communication. This is about 95.95% increase in battery life as compared to direct communication of node 7.

4.1.3 Distance-based work allocation

The distance-based algorithm is implemented using equation 6 and 7 in chapter 3. The network has 30 nodes with distance normally distributed from the base station, using Bluetooth technology and unmodulated nodes has one percent (1%) probability, p of becoming cluster-head. The distance, energy consumed, the number of times seven (7) node becomes cluster-head, and the modulated p value, P_d is displayed in table 4.3 below.

Node	Distance	Energy (J) at 12000s	No of times CH	P_d
1	920	0.0011	13	0.01428
2	940	0.0012	14	0.01367
3	960	0.0012	13	0.01311
4	980	0.0013	13	0.01258
5	1000	9.87E-04	9	0.01208
6	1020	0.0012	11	0.01161
7	1040	0.0012	11	0.01117

Table 4.3. Energy consumed using distance-based algorithm

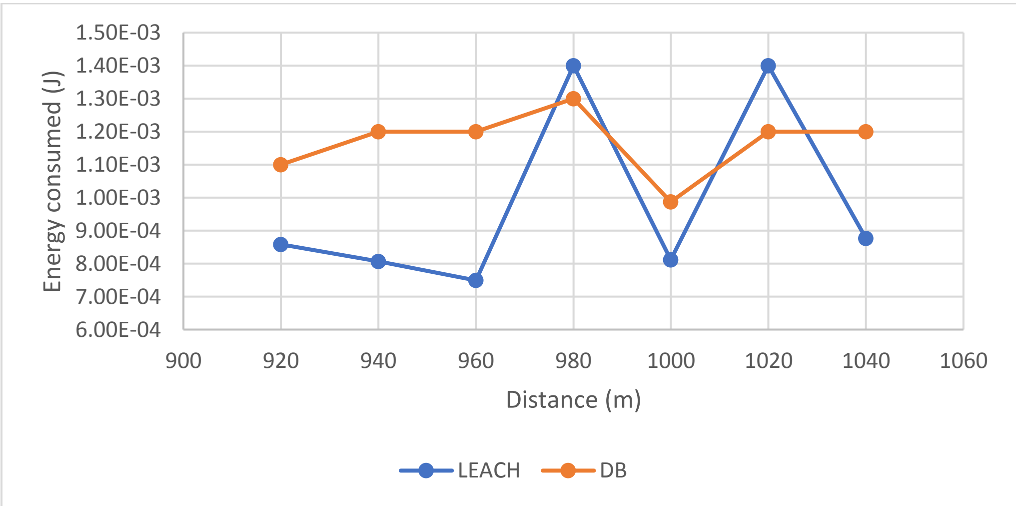

Figure 4.4 Graph of Energy consumed vs distance vs algorithm

Table 4.3 shows that the nodes closer to the base station become cluster-head more often than the nodes further away from the base station. The nodes closer to the base station have been set-up by the distance-based algorithm to have less probability of becoming cluster-head. Figure 4.4 shows that the energy consumed across the network appears more even than that of LEACH algorithm because the distance of the nodes is not incorporated in the algorithm. In essence, the nodes of the network using the distance-based algorithm would die out at approximately the same rate. This enables accurate reading of data across the sensing field because all the nodes are available to sense and send required data from various areas of the sensing field. The sum energy used up by the distance-based algorithm with p value of '0.01' (before modulation) seems higher than LEACH algorithm with p value '0.01' because P_d (distance-based probability) has values higher than p. This can be effectively reduced by reducing the value of p. Future work would involve optimising p values such a node in the cluster is cluster-head and not too many nodes are cluster-head, thus minimizing total energy consumption in the network.

4.2 Mobile nodes

In this section, LEACH and the distance-based algorithm are incorporated into mobile nodes cluster-head election algorithm and the effects are analysed. Firstly, the model simulates 30 mobile nodes using LEACH algorithm with one percent (1%) probability of becoming cluster-head. The simulation is run for 12000 seconds, the energy consumed and number of times seven (7) random nodes is displayed in the table 4.4 below.

Node	Energy (J) at 12000s	No of times CH
1	5.43E-04	10
2	5.96E-04	9
3	3.41E-04	8
4	6.36E-04	12
5	8.90E-04	8
6	5.30E-04	10
7	0.0013	9
Total	4.64E-03	

Table 4.4. Energy consumption of mobile nodes using LEACH

Table 4.4 shows that the energy of the nodes is widely dispersed. The number of times the different nodes become cluster-head is fairly even, this results in higher dissipation of energy for nodes moving further away from the base station. Observing node 3 and 7, they become cluster-head 8 and 9 times respectively which is not a significant difference, but energy expended by node3 is significantly greater than node 7. This difference in energy consumed is due to the path node 3 moves as compared to node 7 shown in Figure 4.5 below.

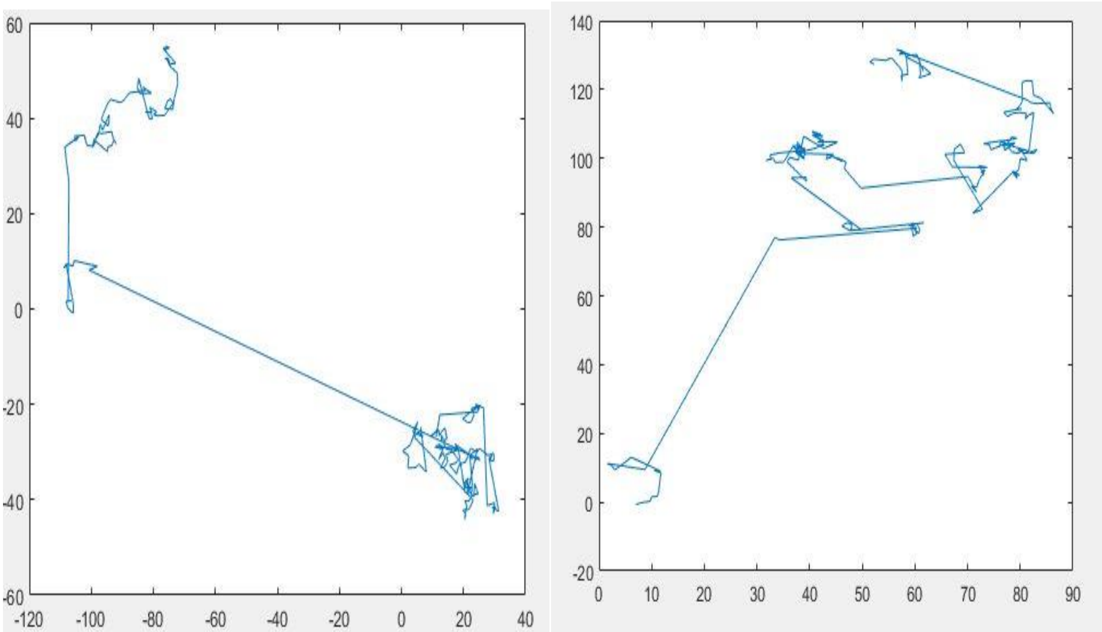

Figure 4.5: Node 7 (left) and node 3 (right) walk path

The base station is set-up at coordinate “500,500”. The mean distance between node 7 and the base station is greater than the mean distance to base station of node 3. LEACH algorithm does not consider distance, therefore, node 7 becomes cluster-head as often as node 3, thus, performing more work due to its work done in transmitting to the base station and dies out faster than node 3.

After the LEACH algorithm is simulated, the distance-based algorithm is run using the same nodes and coordinates used in the LEACH experiment. The energy consumed by the nodes using distance-based algorithm is shown in table 4.5.

Node	Energy (J) at 12000s	No of times CH
1	9.81E-04	15
2	8.87E-04	13
3	9.20E-04	19
4	8.54E-04	13
5	9.18E-04	9
6	8.23E-04	13
7	9.97E-04	9

Table 4.5. Energy consumed using distance-based algorithm

Table 4.5 shows that the energy expended by the nodes is less dispersed than that of LEACH algorithm. The algorithm incorporates the distance of the node from the base station into the cluster-head election. The probability of a node becoming cluster-head modulated such that nodes closer to the base station is higher than the nodes further away, thus, sharing the work between the nodes more evenly. The graph of the probability of becoming cluster-head for node 3 and 7 is shown in figure 4.6.

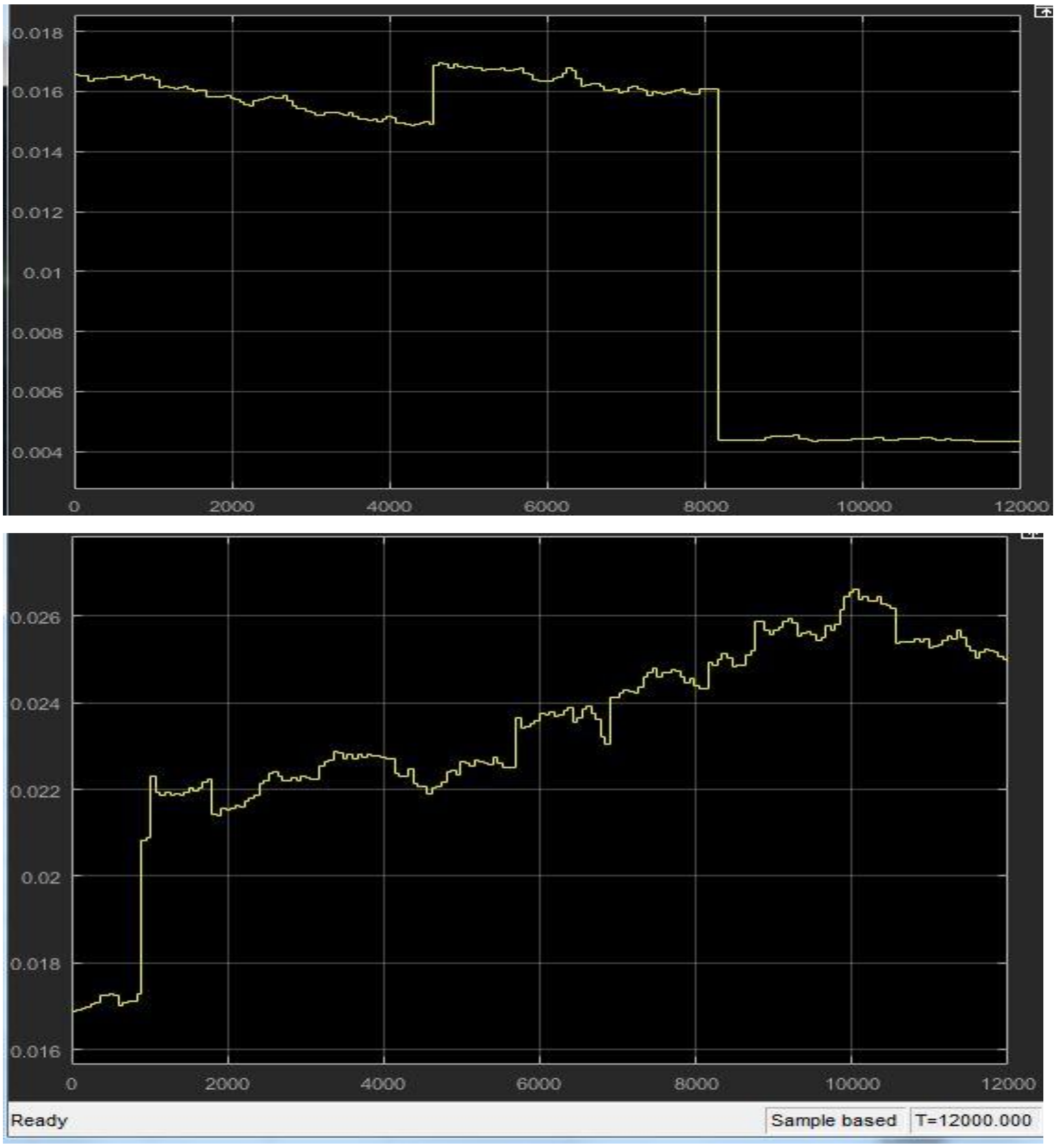

Figure 4.6: Probability of becoming cluster-head for Node 7 (top) and node 3 (bottom).

Figure 4.6 shows the probability of becoming cluster-head for node 3 rising as its distance to the base station is decreasing and that of node 7 decreasing because it is moving further away from the base station.

5. Conclusion

Energy is a major constrain for WSNs. To maintain reliable sensing of the environment (or sensing field), energy efficient network protocols is required. Hierarchical routing techniques, where the nodes are grouped into clusters, and the cluster-head controls the interaction of nodes in its cluster, is more energy efficient than nodes communicating directly to the base station. LEACH protocol ensures that the cluster-head election is fair, such that the nodes in the cluster becomes cluster-head evenly. Distance is a major factor for amount of energy expended during transmission of data from the sensing field to the base station. Nodes with greater transmission distance to the base station in the cluster dies out faster because it performs more work in transmitting data when it is cluster-head. The distance-based algorithm presented in this project, ensures that work is allocated to the nodes in the cluster more evenly. Using the distance-based algorithm, the nodes further away from the base station is allocated less work, thereby balancing the energy across the sensing field. This allows for reliable sensing of the sensor field as the time before first sensor node dies out is improved and data is collected from all areas. LEACH and distance-based algorithm are simulated on Matlab, the results show that the distance-based algorithm allocates work to the nodes more evenly.

6. Future Work

The work performed in this project can be extended in the accompanying future work bearings:

- The nodes in the WSN is simulated to make a trial to become cluster head periodically. In future works, event-driven cluster-head election can be implemented for the nodes. This is useful for emergency applications where significant events in an area in the sensor field needs to be reported speedily. The nodes in the area of the emergency event become cluster-heads and send the data to the base station without waiting for the periodic cluster-head elections.

- Node energy algorithm can also be considered in the cluster-head algorithm of future works, such that nodes with lower battery energy would be allocated less work than nodes with higher energy.

7. References

[1] BRÖRING, "A. et al. New generation sensor web enablement." Sensors, 11, 2011, pp. 26522699. ISSN 1424-8220. Available from: doi:10.3390/s110302652

[2] R. de Fréin, "Quantized nonnegative matrix factorization", *in 19th International, conference on digital signal processing, 2014 pp. 377-382.*

[3] The Official Bluetooth Technology Info Site (July 2018), http://www.bluetooth.com/

[4] Patel, N., Kathiriya, H. and Bavarva, A. (2013). "Wireless sensor network using ZigBee." [online] Pdfs.semanticscholar.org. Available at: https://pdfs.semanticscholar.org/20e2/e765e41c1493f90847d23e9a96f8042b7917.pdf [Accessed 13 Jul. 2018].

[5] Habib F. Rashvand, Ali Abedi, Jose M. Alcaraz-Calero, Paul D. Mitchell, and Subhas Chandra Mukhopadhyay, "Wireless Sensor Systems for Space and Extreme Environments": A Review, *IEEE Sensors Journal,* vol. 14, no. 11, pp. 3955-3970, 2014

[6] Ugaitz Moreno Arocena, "Energy Consumption Studies for 3G Traffic Consolidation on Android using WiFi and Bluetooth*," Master's thesis, Linko ping University, Sweden and Mondragon Univertsitatea*, 2014, pp 40-44

[7] Ekhiotz Jon Vergara and Simin Nadjm-Tehrani, "Watts2Share: Energy-Aware Traffic Consolidation," in *2013 IEEE International conference on Green Computing and communications and IEEE Internet of Things and IEEE Cyber, Physical and Social Computing*, Aug. 2013, pp. 14-22.

[8] X. Lai, Q. Liu, X. Wei, W. Wang, G. Zhou, and G. Han, "A survey of body sensor networks," Sensors, vol. 13, no. 5, pp. 5406–5447, 2013.

[9] R. Silva, Z. Zinonos, J. S. Silva, and V. Vassiliou, "Mobility in WSNs for critical applications," *in Proceedings of the 16th IEEE Symposium on Computers and Communications (ISCC '11),* pp. 451–456, Corfu, Greece, June 2011.

[10] N. D. Lane, E. Miluzzo, H. Lu, D. Peebles, T. Choudhury, and A. T. Campbell, "A survey of mobile phone sensing," *IEEE Communications Magazine, vol. 48, no. 9*, pp. 140–150, Sep. 2010.

[11] W. R. Heinzelman, A. Chandrakasan, and H. Balakrishnan, "Energy- efficient communication protocol for wireless microsensor networks," in *Proceedings of the 33rd Annual Hawaii International Conference on System Sciences*, vol. 2, Jan. 2000, p. 10.

[12] S. Rani and S. H. Ahmed, "Multi-hop Network Structure Routing Protocols", Elsevier, (2016).

[13] R. Loomba, R. de Fréin, and B. Jennings, "Selecting energy efficient cluster-head trajectories for collaborative mobile sensing," in 2015 IEEE Global Communications Conference (GLOBECOM), Dec. 2015, pp. 1– 7.

[14] Chunyao Fu, Zhifang Jiang, Wei WEI and Ang WEI, "An Energy Balanced Algorithm of LEACH Protocol in WSN," *IJCSI International Journal of Computer Science Issues*, Vol. 10, Issue 1, No 1, January 2013, pp. 354-359.

[15] Injong Rhee, Minsu Shin, Seongik Hong, Kyunghan Lee, Seong Joon Kim and Song Chong, "On the Levy-Walk Nature of Human Mobility*," IEEE/ACM Transactions On Networking*, vol. 19, no. 3, June 2011, pp. 630-643.

[16] Xianchao Xu and Zhongjie Wang, "Networked modeling and simulation based on SimEvents," *2008 Asia Simulation Conference - 7th International Conference on System Simulation and Scientific Computing*, Beijing, 2008, pp. 1421-1424.

[17] MatlabHelpOnline.com. (2018). *SimEvents in Matlab*. [online] Available at: https://www.Matlabhelponline.com/simevents-in-Matlab-assignment-help-17669
[Accessed 1 Aug. 2018].

[18] De Fréin R. APHONIC: Adaptive thresholding for noise cancellation in smart mobile environments. In: 2017 IEEE 13th International Conference on Wire- less and Mobile Computing, Networking and Communications (WiMob); 2017. p. 285–292.

[19] Tung, Y. (2018). *Acoustic Sensing: Mobile Applications and Frameworks*. [online] Kabru.eecs.umich.edu. Available at: https://kabru.eecs.umich.edu/wordpress/wp-content/uploads/thesis_yctung_fianl.pdf [Accessed 10 Aug. 2018].

[20] Internet of things: wireless sensor networks. (2014). Ginevra: IEC.

[21] R. de Fréin, Learning and storing the parts of objects, IMF", *in IEEE internation workshop on machine learning for signal processing 2014, pp. 1-6.*

Appendix

xxxxxxxxxDistance computationxxxxxxxxxxxx

```
No_Users = 30;

s = 210; alpha = 1.5;

base = [500, 500];

X = zeros(No_Users, s);

Y = zeros(No_Users, s);

D = zeros(No_Users, s, No_Users);

    for node =  1: No_Users

      [X(node, :), Y(node, :)] = levywalkfunc(alpha, s);

    end

    for node  = 1:No_Users

      D(:, :, node) = sqrt((X(node, :) - X).^2 + ...

        (Y(node, :) - Y).^2);

    end

    D_base = sqrt((X - base(1,1)).^2 + ...

      (Y - base(1,2)).^2);

figure, plot(X', Y')
```

xxxxxxxxxxxxLevywalkfunctionxxxxxxxxxxxxxxxxxxxxxx

```
    function [x,y] = levywalkfunc(alpha,s)
```

```
        x=zeros(1,s); y=zeros(1,s);

    for n=2:s

        theta=rand*2*pi;

        f=rand^(-1/alpha);

        x(n)=x(n-1)+f*cos(theta);

        y(n)=y(n-1)+f*sin(theta);

end
```